4. DEMAND VS. CAPACITY

4.1 Performance Criteria

4.1.1 Global Displacement Criteria

Each bridge or frame shall satisfy equation 4.1. Where Δ_D is the displacement along the local principal axes of a ductile member generated by seismic deformations applied to the structural system as defined in Section 2.1.2.[4]

$$\Delta_D < \Delta_C \tag{4.1}$$

Where:

Δ_D Is the displacement generated from the global analysis, the stand-alone analysis, or the larger of the two if both types of analyses are necessary.

Δ_C The frame displacement when any plastic hinge reaches its ultimate capacity, see Figure 4.1.

4.1.2 Demand Ductility Criteria

The entire structural system as well as its individual subsystems shall meet the displacement ductility demand requirements in Section 2.2.4.

4.1.3 Capacity Ductility Criteria

All ductile members in a bridge shall satisfy the displacement ductility capacity requirements specified in Section 3.1.4.1.

[4] The SDC development team elected not to include an interaction relationship for the displacement demand/capacity ratios along the principal axes of ductile members. This decision was based on the inherent factor of safety provided elsewhere in our practice. This factor of safety is provided primarily by the limits placed on permissible column displacement ductility and ultimate material strains, as well as the reserve capacity observed in many of the Caltrans sponsored column tests. Currently test data is not available to conclusively assess the impact of bi-axial displacement demands and their effects on member capacity especially for columns with large cross sectional aspect ratios.

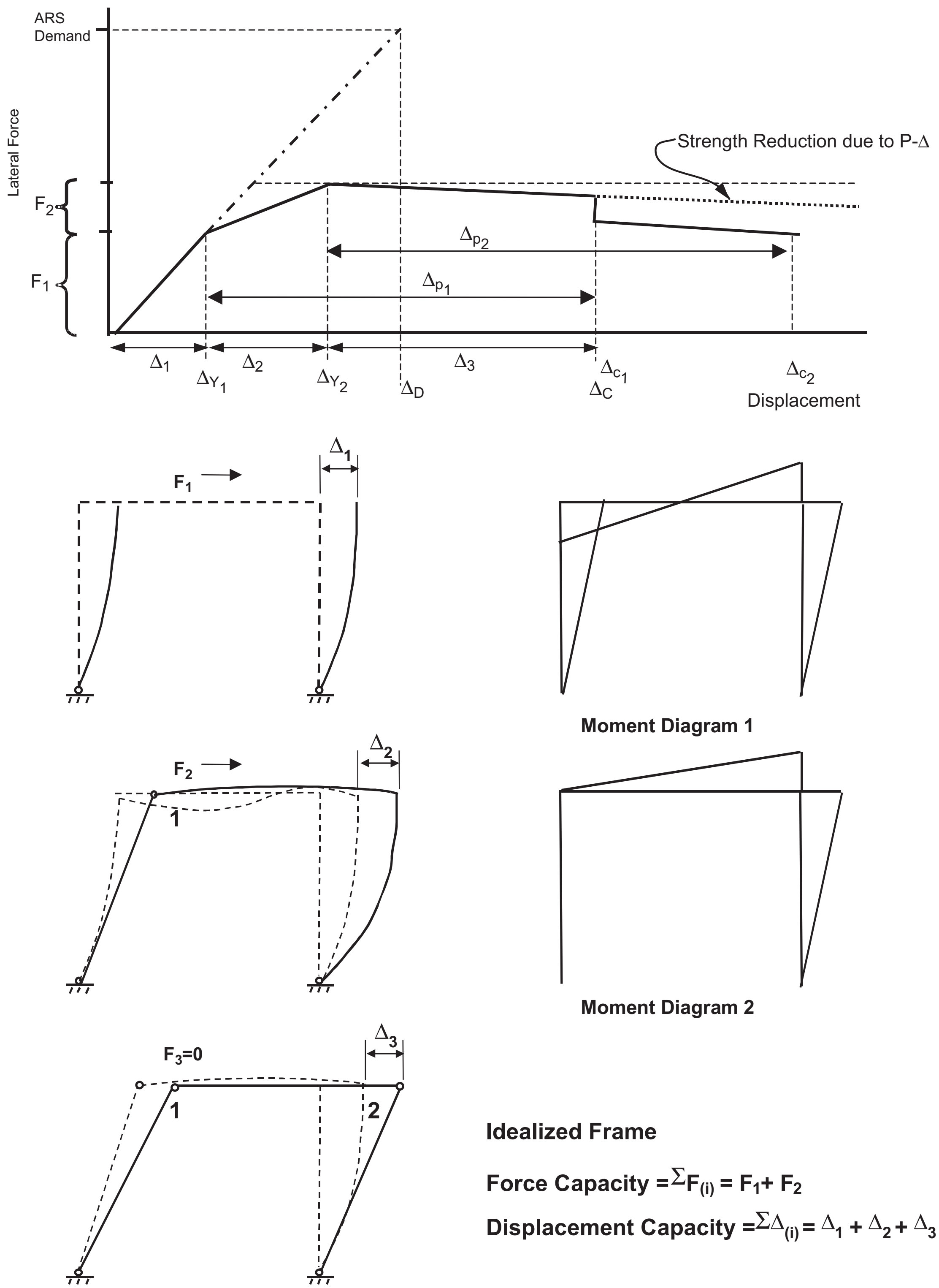

Figure 4.1 Global Force Deflection Relationship [4], [7]

4.2 P-Δ Effects

The dynamic effects of gravity loads acting through lateral displacements shall be included in the design. The magnitude of displacements associated with *P-Δ* effects can only be accurately captured with non-linear time history analysis. In lieu of such analysis, equation 4.3 can be used to establish a conservative limit for lateral displacements induced by axial load for columns meeting the ductility demand limits specified in Section 2.2.4. If equation 4.3 is satisfied, *P-Δ* effects can typically be ignored.[5] See Figure 4.2. [4]

$$P_{dl} \times \Delta_r \leq 0.20 \times M_p^{col} \tag{4.3}$$

Where:

Δ_r = The relative lateral offset between the point of contra-flexure and the base of the plastic hinge. For Type I pile shafts $\Delta_r = \Delta_D - \Delta_s$

Δ_s = The pile shaft displacement at the point of maximum moment

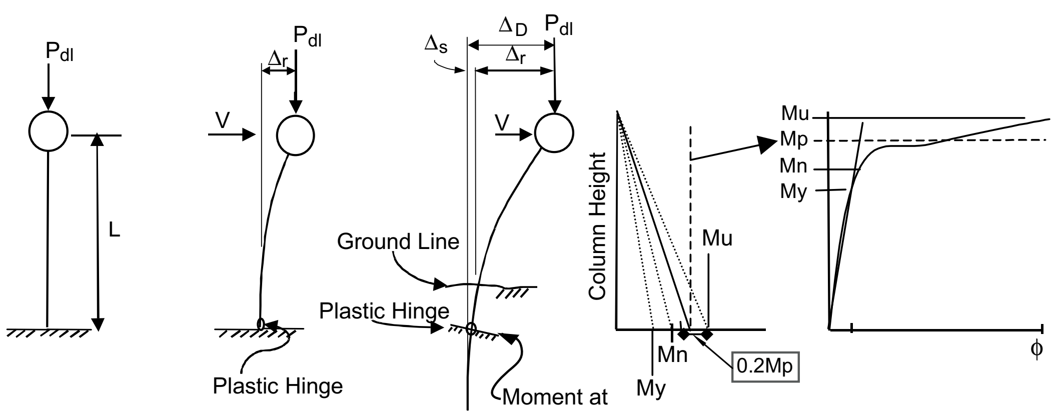

Figure 4.2 P-Δ Effects on Bridge Columns [4]

4.3 Component Overstrength Factors

4.3.1 Column Overstrength Factor

In order to determine force demands on essentially elastic members, a 20% overstrength magnifier shall be applied to the plastic moment capacity of a column to account for:

- Material strength variations between the column and adjacent members (e.g. superstructure, bent cap, footings, oversized pile shafts)
- Column moment capacities greater than the idealized plastic moment capacity

$$M_o^{col} = 1.2 \times M_p^{col} \tag{4.4}$$

[5] The moment demand at point of maximum moment in the shaft is shown in Figure 4.2. As the displacement of top of column is increased, moment demand values at the base pass through My, Mn, Mp, and Mu (key values defining the moment-curvature curve, see Figure 4.2). The idealized plastic moment Mp is always less than Mu in a well-confined column and 0.2Mp allowance for the P-Δ effects is justifiable, given the reserve moment capacities shown above.

4.3.2 Superstructure/Bent Cap Demand & Capacity

The nominal capacity of the superstructure longitudinally and of the bent cap transversely must be sufficient to ensure the columns have moved well beyond their elastic limit prior to the superstructure or bent cap reaching its expected nominal strength M_{ne}. Longitudinally, the superstructure capacity shall be greater than the demand distributed to the superstructure on each side of the column by the largest combination of dead load moment, secondary prestress moment, and column earthquake moment. The strength of the superstructure shall not be considered effective on the side of the column adjacent to a hinge seat. Transversely, similar requirements are required in the bent cap.

Any moment demand caused by dead load or secondary prestress effects shall be distributed to the entire frame. The distribution factors shall be based on cracked sectional properties. The column earthquake moment represents the amount of moment induced by an earthquake, when coupled with the existing column dead load moment and column secondary prestress moment, will equal the column's overstrength capacity, see Figure 4.3. Consequently, the column earthquake moment is distributed to the adjacent superstructure spans.

$$M_{ne}^{\sup(R)} \geq \sum M_{dl}^{R} + M_{p/s}^{R} + M_{eq}^{R} \tag{4.5}$$

$$M_{ne}^{\sup(L)} \geq \sum M_{dl}^{L} + M_{p/s}^{L} + M_{eq}^{L} \tag{4.6}$$

$$M_{o}^{col} = M_{dl}^{col} + M_{p/s}^{col} + M_{eq}^{col} \tag{4.7}$$

$$M_{eq}^{R} + M_{eq}^{L} + M_{eq}^{col} + \left(V_{o}^{col} \times D_{c.g.}\right) = 0 \tag{4.8}$$

Where:

$M_{ne}^{\sup R,L}$	=	Expected nominal moment capacity of the adjacent left or right superstructure span
M_{dl}	=	Dead load plus added dead load moment (unfactored)
$M_{p/s}$	=	Secondary effective prestress moment (after losses have occurred)
M_{eq}^{col}	=	The column moment when coupled with any existing dead load and/or secondary prestress moment will equal the column's overstrength moment capacity
$M_{eq}^{R,L}$	=	The portion of M_{eq}^{col} and $V_{o}^{col} \times D_{c.g.}$ (moment induced by the overstrength shear) distributed to the left or right adjacent superstructure span

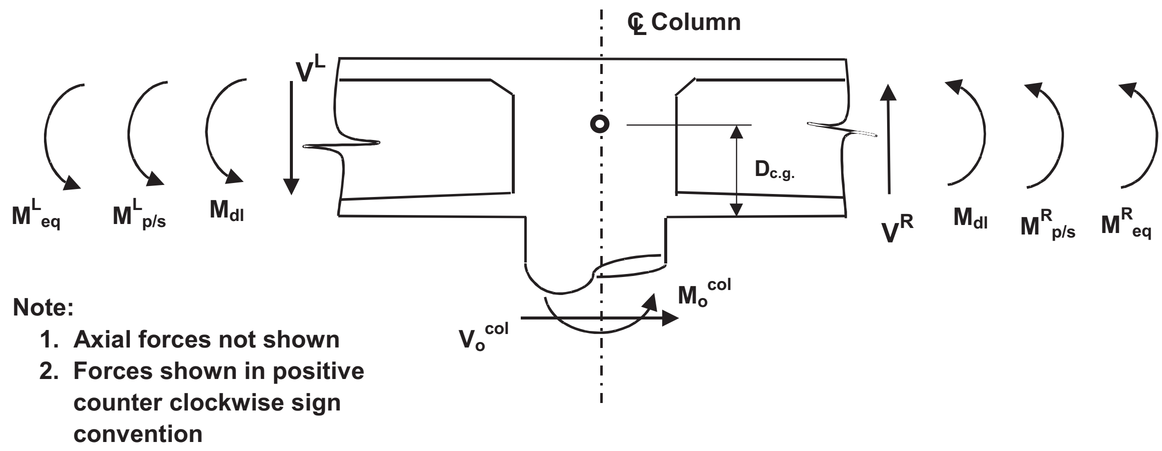

Figure 4.3 Superstructure Demand Generated by Column Overstrength Moment

4.3.2.1 Longitudinal Superstructure Capacity

Reinforcement can be added to the deck, A_s and/or soffit A_s' to increase the moment capacity of the superstructure, see Figure 4.4. The effective width of the superstructure increases and the moment demand decreases with distance from the bent cap, see Section 7.2.1.1. The reinforcement should be terminated after it has been developed beyond the point where the capacity of the superstructure, $M_{ne}^{\sup}$ exceeds the moment demand without the additional reinforcement.

4.3.2.2 Bent Cap Capacity

The effective width for calculating bent cap capacity is defined in section 7.3.1.1. Bent cap reinforcement required for overstrength must be developed beyond the column cap joint. Cutting off bent cap reinforcement is discouraged because small changes in the plastic hinge capacity may translate into large changes in the moment distribution along the cap due to steep moment gradients

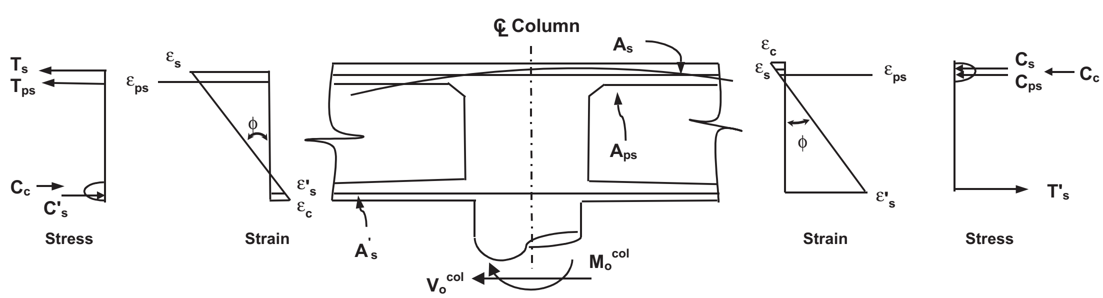

Figure 4.4 Capacity Provided by Superstructure Internal Resultant Force Couple

4.3.3 Foundation Capacity

The foundation must have sufficient strength to ensure the column has moved well beyond its elastic capacity prior to the foundation reaching its expected nominal capacity, refer to Section 6.2 for additional information on foundation performance.